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MARCH 21, 1988
CHEMICAL & ENGINEERING

NEWS

RUBBER

Slow-growing tire industry continues to dominate demand

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NEWS
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MARCH 21, 1988

News of the Week

■ **NASA study provides first strong evidence for serious ozone depletion outside Antarctica, places blame on chlorofluorocarbons.** **Page 6**

■ **Henkel Group's U.S. subsidiary has named a new president and launched an extensive reorganization program.** **Page 7**

■ **Claims against Monsanto's Searle unit over infections allegedly caused by Searle's discontinued Copper-7 birth-control device could escalate as a result of new evidence in a St. Paul, Minn., court case.** **Page 7**

■ **EPA has opted not to review the carcinogenic potential of the herbicide 2,4-D, drawing praise from Dow Chemical and criticism from environmental groups.** **Page 8**

■ **House subcommittee hearings on plans to build the Superconducting Super Collider probe funding of project, raise questions about extent of foreign support.** **Page 8**

Business

Productivity of the U.S. chemical industry continued to improve in 1987, but the rate of increase was slower than in 1986. **Page 11**

Government

Congress is considering legislation on a variety of topics of scientific interest including clean air amendments, pesticide registration. **Page 14**

Space station, defense research. NIH grants are among the programs federal budgeters would consider cutting to reduce deficit. **Page 16**

Science

Method for asymmetric dihydroxylation of olefins installs asymmetric configurations at two carbon atoms at once. **Page 19**

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Technology

Aluminophosphate-based molecular sieves with pores greater than 10 Å show potential as cracking catalysts for petroleum refining. **Page 22**

Books

"Emergency Response to Chemical Accidents: Planning and Coordinating Solutions" by James T. O'Reilly is a useful primer for those new to coordinating emergency response plans. **Page 53**

Cover: All-terrain vehicle tire is removed from mold at Goodyear's Madisonville, Ky., specialty tire plant

Product Report

Outlook for rubber is moderately optimistic, with global consumption growing about 2% annually over the next five years to nearly 16 million metric tons in 1992. **Page 25**

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Chemical & Engineering News

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LETTERS

Chemistry in the future

SIR: As I write, I am looking both at my 1987–88 dues and Paul G. Gassman's article, "Will chemistry exist in the future?" (C&EN, Dec. 14, 1987, page 51). Perhaps his question and what I feel I do not get for my dues are facets of a more serious deep-seated problem that has not yet been appropriately and directly articulated.

Let me answer his question. "Chemistry" certainly will exist in the future. The fundamental realities defined by that word, whatever they are, always have and always will exist. In another sense, chemistry, as we know it, is fated to disappear just as the chemistry of Lavoisier and Arrhenius, as they knew it, disappeared. I am not particularly troubled by his concern that there is a decline in the quantity and quality of U.S. students choosing Chemistry (note the capital) as a career. The former is a matter of fashion and government funding; the latter is truly debatable. Perhaps of more concern is what kind of education those who choose Chemistry are receiving.

The question that I really believe he is asking is, "Will ACS exist in the future?" I, of course, do not know the answer to that question, but I can express a hope. And that hope is that it does not do so in its present form or with its present priorities—whatever they really may be. Despite president Nelson's sanguine view, ACS has not been effective in representing chemistry or chemists either in the public eye or in the marketplace. That is not my judgment alone; the bill of particulars is to be found in Gassman's article, and in the passive ways ACS reports layoffs, in the rising tide of complaints arising in C&EN, and in the poor participation in local affairs.

I do not pretend to have the right answers and what suggestions I might make would make this letter too long, but I believe the society would be well served by a vigorous open debate of its function and how it can best serve both chemistry and chemists. The membership may decide it cannot do both effectively. If so, that is something the membership should know. I, thus, believe that the best return I could receive this year for my dues would be for the ACS officers and staff to provide the forums, both in C&EN and at local, regional, and national meetings, for these views to be expressed.

George W. Latimer Jr.
Bryan, Tex.

Memoirs of Henry Gilman

SIR: At the request of the Royal Society of London I am writing the biographical memoir of Henry Gilman, who was a foreign member of the society. I would be most grateful to receive from those who were associated with him any information about him that they think may be relevant for the memoir, including personal anecdotes that throw light on his character and style of working. Material relating to the period before about 1945 would be especially helpful.

Colin Eaborn
MOLS, University of Sussex
Brighton BN1 9QJ, England

The Bhopal crisis

SIR: Wil Lepkowski's uncritical review of "Bhopal: Anatomy of a Crisis" (C&EN, Jan. 11, page 24) cannot be allowed to pass without comment. His generally positive verdict manages to miss the major faults in the book.

The worst of these relates to definitions and is apparent right from the beginning. What is a crisis and why is it important? How would knowledge of the "anatomy of a crisis" be put to constructive use in industrial or public safety considerations? The author does not say. Nowhere in the book is "crisis" defined clearly or the benefits of understanding it explained.

The consequences of this become evident in Chapter 6 where Shrivastava states, "and even if deaths and injuries were inevitable, Bhopal would not have become a worldwide crisis if the different parties had worked together to alleviate aftereffects." What on earth is this? Has the avoidance of something called a "crisis" now become a priority? People may die, but at all costs we must avoid "crises." The implications are offensive.

The book has a number of other faults including the author's inability to avoid using emotive language. The accident was without doubt enough to appall anyone, but isn't this the best reason for some clear-headed analysis to find out exactly what happened and determine ways of avoiding similar events in the future?

Keith Weaver
Toronto, Ontario, Canada

Don't jargon it

SIR: In the interest of keeping life as simple as possible, and since we spend almost all our time communicating with people who speak our own language, it is important to minimize professional

Chemical Productivity Continues To Increase, But More Slowly

William J. Storck, C&EN New York

Productivity in the U.S. chemical industry continued to improve in 1987, but the rate of growth slowed from the year before. And toward the end of the year, productivity advances all but halted.

Using data published by the federal government, C&EN estimates that productivity for the chemicals and allied products industry rose 3.9% from 1986. Productivity is output per workhour, calculated by dividing the index for production by the index for workhours of production employees. The increase in 1987 is far below the 5.5% increase in 1986 and is the lowest growth rate for the chemical industry since 1982, when the recession-plagued industry's productivity fell 1.5%.

During the early 1980s, the chemical industry worked to trim employee rolls and to introduce production efficiencies into its plants. These steps, combined with natural productivity increases seen during recovery from recession, worked to provide large productivity increases. However, as the U.S. economy enters its sixth year of recovery, there are signs that productivity improvements from a trimmer work force have run their course.

These trends are reinforced by unit labor cost data, which also showed signs of declining improvement in 1987. Unit labor costs are labor costs per unit of output, calculated by dividing the index for wages by the productivity index. Labor costs (which would decline to show improvement) fell just 0.5% in 1987 from 1986. This compares

Productivity growth slowed for chemicals in 1987. . .

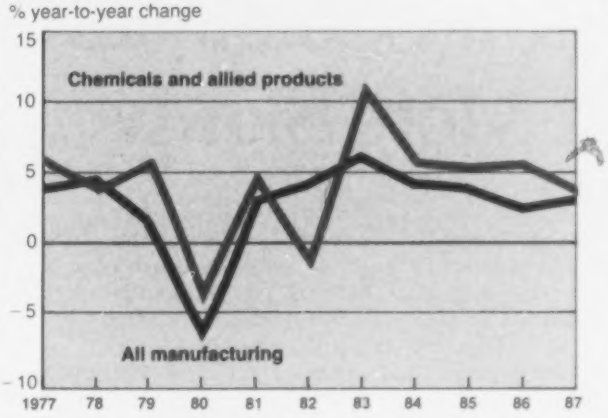
Indexes, 1977 = 100	1987	1986	1985	1984	1983	1982	1981	1980	1979	1978	1977
CHEMICALS AND ALLIED PRODUCTS											
Production	140.0	133.0	127.1	121.6	113.9	103.8	112.6	106.4	113.3	106.3	100.0
Workhours	94.8	93.5	94.3	95.0	93.9	95.2	101.7	101.0	103.1	102.2	100.0
Productivity	147.7	142.2	134.8	128.0	121.3	109.0	110.7	105.4	109.9	104.0	100.0
Hourly production wages	192.4	186.1	180.1	172.7	164.8	155.0	141.8	129.2	118.2	109.2	100.0
Unit labor costs	130.3	130.9	133.7	135.0	135.9	142.2	128.2	122.6	107.6	105.0	100.0
ALL MANUFACTURING											
Production	134.6	129.2	126.4	123.4	113.9	102.2	110.5	108.2	110.7	106.1	100.0
Workhours	93.6	93.0	93.3	94.8	88.2	87.0	97.9	98.9	106.4	104.5	100.0
Productivity	143.8	138.8	135.5	130.1	124.8	117.5	112.9	109.4	104.2	101.5	100.0
Hourly production wages	174.4	171.1	166.9	161.5	155.4	149.6	140.7	128.1	118.0	108.6	100.0
Unit labor costs	121.6	123.3	123.2	124.1	124.4	127.3	124.7	121.5	113.2	107.0	100.0

. . .and fell in final two quarters of the year

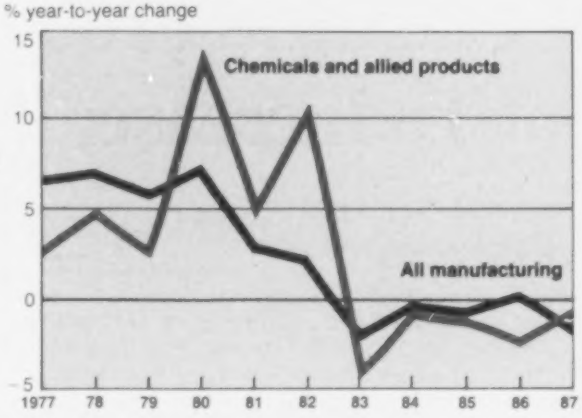
	Quarters, 1987				Quarters, 1986				Quarters, 1985		
Indexes, 1977 = 100	4th	3rd	2nd	1st	4th	3rd	2nd	1st	4th	3rd	2nd
CHEMICALS AND ALLIED PRODUCTS											
Production	144.2	141.8	138.2	135.8	133.6	134.1	132.8	131.3	127.9	128.1	126.8
Workhours	97.1	95.5	93.3	93.2	94.2	93.4	93.1	93.4	93.8	93.9	94.5
Productivity	148.5	148.6	148.2	145.7	141.9	143.6	142.7	140.6	136.3	136.4	134.1
Hourly production wages	195.5	193.2	191.2	189.8	188.8	186.9	184.8	184.1	183.9	180.7	178.6
Unit labor costs	131.7	130.0	129.0	130.3	133.1	130.2	129.5	130.9	134.9	132.5	133.1
ALL MANUFACTURING											
Production	137.9	135.7	133.2	131.6	130.4	129.4	128.4	128.4	127.4	126.8	126.2
Workhours	95.3	93.5	92.8	92.8	93.1	92.6	92.8	93.6	93.5	92.9	93.0
Productivity	144.7	145.2	143.6	141.8	140.1	139.7	138.3	137.3	136.3	136.5	135.6
Hourly production wages	176.3	174.5	173.7	173.2	172.1	171.0	170.8	170.5	169.4	167.8	167.0
Unit labor costs	121.8	120.2	121.0	122.2	122.9	122.4	123.5	124.2	124.3	122.9	123.2

Sources: Federal Reserve Board, Department of Labor, C&EN estimates

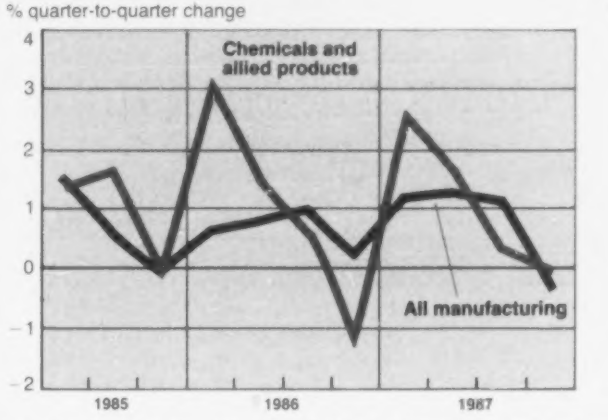
Annual productivity growth is still better for chemicals . . .



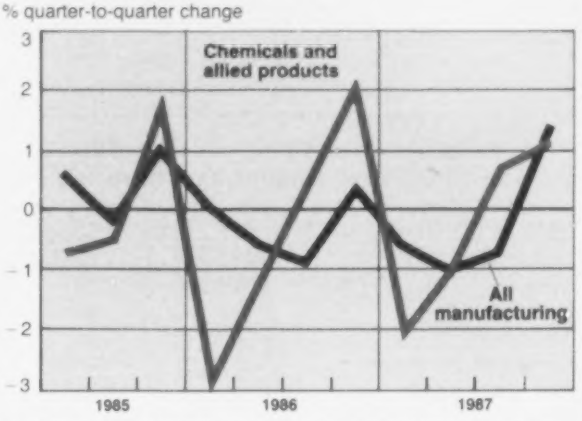
. . . but unit labor costs fell more for manufacturing in 1987



Quarterly growth has slowed considerably for chemical productivity . . .



. . . and unit labor costs began to escalate at the end of 1987



Note: Productivity is output per workhour, calculated by dividing indexes for production by indexes for workhours of production employees. Unit labor costs are labor costs per unit of output, calculated by dividing indexes for wages by indexes for output per workhour. **Sources:** Federal Reserve Board, Department of Labor, C&EN estimates

with a drop of 2.1% in 1986 and is again the poorest showing since 1982.

In spite of slowing improvement, the chemical industry outperformed the all-manufacturing category in productivity, but lagged in unit labor cost improvement last year. C&EN calculates that productivity for all manufacturing improved 3.6% in 1987 following a slow 2.4% improvement in 1986. Unit labor costs for all manufacturing declined a much better 1.4% in 1987, after remaining essentially unchanged in 1986.

Further signs that chemical industry productivity increases may be slowing came in the final two quarters of 1987, in which seasonally adjusted quarter-to-quarter data show a flattening of productivity and actual increases in unit labor costs.

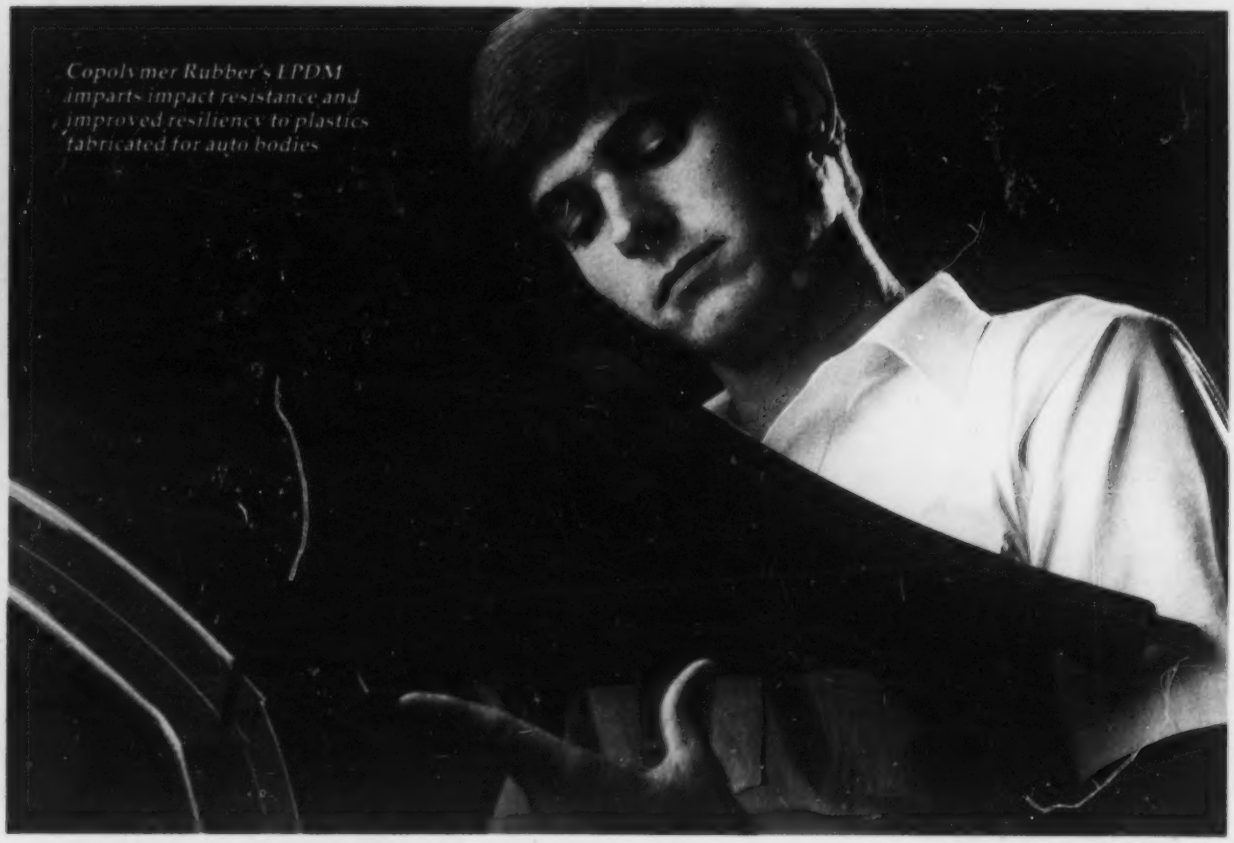
In the fourth quarter, productivity for the chemical industry was unchanged from the third quarter, which itself was up only 0.3% from the preceding three months. And unit labor costs in the fourth quarter actually increased, rising 1.3% from the third quarter, which had been up 0.8% from the second quarter.

For all manufacturing, fourth-quarter productivity declined 0.3% following a 1.1% improvement in the third quarter. Unit labor costs for all manufacturing increased 1.3% in the fourth quarter, slightly faster than for the chemicals and allied products sector, following a 0.7% decline in the previous period.

Even on a year-to-year basis, the quarterly data are showing mixed signals. For the fourth quarter, year-to-year productivity in the chemical industry increased 4.7%, following a 3.5% increase in the third quarter. But unit labor costs in the fourth quarter shot up, rising 3.0% from fourth-quarter 1986, following a decline of 0.2% in the third quarter.

For all manufacturing, productivity in the fourth quarter increased 3.3% on an annual basis, following an improvement of 3.9% in the third quarter. Unit labor costs declined 0.9% in the fourth quarter on an annual basis, following a decline in the third quarter of 1.8%.

Two quarters' data are not enough to show that productivity improvement has ceased for the chemical industry, but as the industry enters its traditionally strongest quarters of the year, the trend bears watching. □



Copolymer Rubber's EPDM imparts impact resistance and improved resiliency to plastics fabricated for auto bodies

Modest Growth Ahead for Rubber

Bruce F. Greek, C&EN Houston

For the past 10 years, the rubber industry has had little to cheer about. Now, although no cause for wild celebration, there may be reason to expect business to be slightly better.

The five-year forecast for worldwide rubber consumption calls for growth averaging 2% annually, according to the International Institute of Synthetic Rubber Producers (IISRP). That follows an upbeat year in 1987, when worldwide consumption apparently grew even more than 2%. However, while moving ahead, this mature industry will have few spectacular developments in demand for its products through the early 1990s.

According to IISRP's forecast, production of both synthetic and natural rubbers will grow in line with demand; no significant inventory building is expected. Synthetic rubber capacity also will grow moderately, and most capacity additions in North America will be for smaller-volume and specialty rubbers.

By 1992, worldwide consumption of synthetic and natural rubber will be 15.9 million metric tons, according to William E. Tessmer, IISRP's managing director. That will be an 11% rise from the 14.4 million metric tons estimated for 1987. Last year's consumption is estimated to have risen 3.3% over 1986's 13.9 million metric tons. About 68% of all new rubber consumed worldwide last year was synthetic.

Data on consumption and production of rubber are compiled by IISRP, an association of 51 synthetic rubber producers located in noncommunist countries. Its member companies provide more than 95% of the world's synthetic rubber produced in noncommunist nations.

According to IISRP, 1987 global consumption of synthetic rubber, including communist countries, increased 3.1% from 1986 to 9.75 million metric tons. In the U.S. and Canada, combined consumption increased 3.3% to 2.52 million metric tons last year, reversing the trend of recent annual declines. Synthetic rubber demand is forecast to continue growing in these two countries—but only modestly—for a 1.5% increase over the next five years to 2.56 million metric tons in 1992.

In other parts of the world, consumption is expected to grow much faster. In Latin America, for instance, synthetic rubber demand, although growing from a smaller base of 541,000 metric tons, is forecast to grow almost 20% in the five-year period to 648,000 metric tons. In

the Asia/Oceania region, excluding communist countries, consumption is forecast to grow 16% overall to 1.74 million tons by 1992. Combined use in Western Europe, Africa, and the Middle East is expected to increase about 7.5% during the same period to 2.12 million metric tons.

IISRP forecasts that total rubber consumption in all communist countries will increase 16% during the next five years, reaching nearly 4.7 million metric tons in 1992, with 20% of that natural rubber. China and other Asian communist countries, including North Korea and Vietnam, will remain the only area of the world where more natural rubber than synthetic rubber is consumed. In those countries, however, synthetic rubber consumption is increasing faster than that of natural rubber, so synthetic's share will grow to 41% in 1992 from 40% in 1987 and 39% in 1986. In Eastern Europe, including the U.S.S.R., synthetic rubber consumption accounted for 88% of the 3.3 million metric-ton total last year. By 1992, that share will increase to about 90% as synthetic rubber use rises from 2.9 million metric tons to 3.3 million metric tons.

In noncommunist countries, natural rubber consumption is forecast to grow 9.5% overall in the five-year period. In Canada and the U.S., combined consumption is expected to remain essentially unchanged, but combined use in Western Europe, Africa, and the Middle East will increase about 7% to 1.16 million metric tons. Asia/Oceania's share of noncommunist countries' total natural rubber consumption also will increase, from 42% last year to almost 44% in 1992, representing a 15% increase over the period to 1.8 million metric tons. Latin America will have the fastest growth of any geographic area in demand for natural rubber, at 20%, with consumption there rising to 296,000 metric tons.

In noncommunist countries last year, synthetic rubber accounted for 63.4% of total new rubber consumption, according to IISRP. That share will remain fairly steady, declining only slightly to 63.1% by 1992. By then, natural rubber consumption will exceed 4 million metric tons and synthetic rubber will exceed 7 million metric tons.

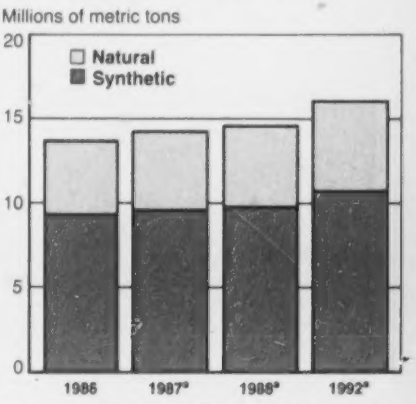
Styrene-butadiene rubber (SBR) will continue to be the largest-volume synthetic rubber produced and used in noncommunist countries. Consumption of both solid and latex forms totaled 2.58 million metric tons in 1986 and rose to 2.63 million metric tons in 1987, according to IISRP. Consumption is forecast to reach 2.66 million metric tons in 1988, and 2.82 million metric tons in 1992. Spurred by growing use in paper coatings, demand for another form—carboxylated SBR latex—is predicted to rise from 890,000 metric tons in 1986 to 1.02 million metric tons in 1992.

Among the other synthetic rubbers, polybutadiene ranks second to SBR in volume used. Total consumption in noncommunist countries in 1986 was just under 1 million metric tons and grew 6% last year to 1.06 million metric tons and is forecast to increase 7.7% over the next five years to reach 1.14 million metric tons in 1992.

The various ethylene-propylene rubbers are third in volume at 465,000 metric tons consumed in noncommunist countries in 1986. Consumption rose to 494,000 metric tons last year and is forecast to rise to 501,000 metric tons this year and to 556,000 metric tons in 1992, representing a five-year growth of 13%.

For smaller-volume synthetic rubbers, IISRP forecasts that polychloroprene consumption will grow to 268,000 metric tons in 1992 from 258,000 metric tons in 1987. Nitrile rubbers, in both the solid and latex forms, will increase 10% in the 1987-92 period, rising to 238,000 metric tons in 1992 from 216,000

Worldwide demand for natural and synthetic rubber rises



a Estimated. **Source:** International Institute of Synthetic Rubber Producers

Modest increases forecast for rubber consumption

Thousands of metric tons	U.S. & Canada		Western Europe		Latin America		Asia & Oceania		Africa & Middle East		Total	
	1987	1992	1987	1992	1987	1992	1987	1992	1987	1992	1987	1992
Styrene-butadiene[a]	839	833	727	745	329	386	674	783	63	72	2,632	2,819
Carboxylated styrene-butadiene	447	458	335	370	21	29	125	152	5	6	933	1,015
Polybutadiene	422	424	240	257	109	131	270	309	19	21	1,060	1,142
Ethylene-propylene diene	204	216	170	195	11	16	107	126	2	3	494	556
Polychloroprene	86	85	81	77	19	23	68	78	5	5	259	268
Nitrile	58	66	81	85	13	17	51	66	3	4	216	238
Other synthetics[b]	457	479	216	244	39	46	197	223	22	33	931	1,025
TOTAL SYNTHETIC	**2523**	**2561**	**1850**	**1973**	**541**	**648**	**1492**	**1737**	**119**	**144**	**6,525**	**7,063**
Natural	872	871	945	980	247	296	1568	1804	140	180	3,771	4,131
TOTAL RUBBER	**3395**	**3432**	**2460**	**2953**	**788**	**944**	**3060**	**3541**	**259**	**324**	**10,296**	**11,194**

Note: Excludes communist countries. a Solid and latex forms of SBR. b Includes polyisoprene and butyl. **Source:** International Institute of Synthetic Rubber Producers

metric tons in 1987. Consumption of all other synthetic rubbers (including butyl and polyisoprene rubbers), as well as the many specialty rubbers, is forecast to grow to 1.03 million metric tons in 1992 from 931,000 metric tons in 1987.

As has been the case for many years, tires continue to dominate rubber use. About half of all rubber consumption goes into making tires. In noncommunist countries, on a weighted-average basis, IISRP says, tires and tire products consume 43% of all synthetic rubber and 62% of natural rubber. In the U.S. and Canada, tires and tire products account for 43% of synthetic rubber consumption, and 72% of natural rubber consumption. In Western Europe, 35% of synthetic rubber consumption goes into tires, along with 66% of natural rubber. In Latin America, tires and tire products take the largest shares of rubber consumption among areas of the world, at 62% of synthetic and 77% of natural.

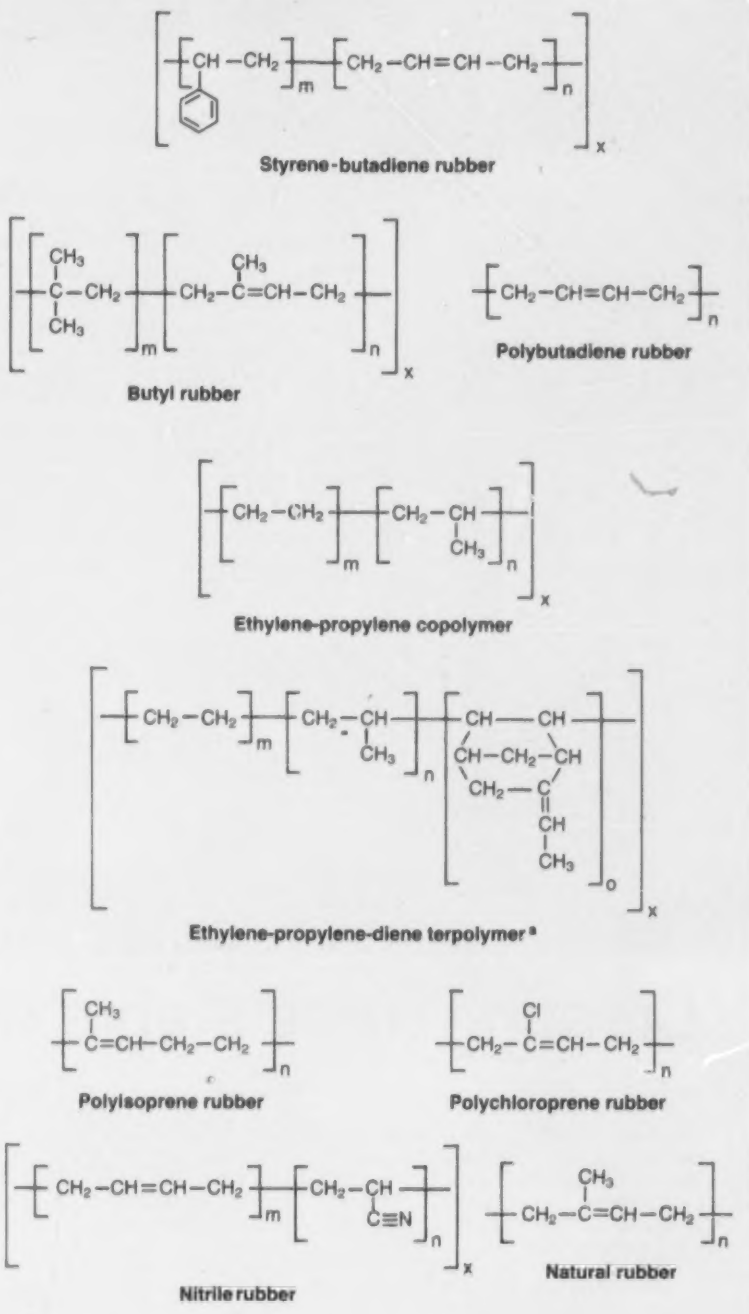
In the U.S., synthetic rubber production has grown to meet domestic and expanding export demands. Total synthetic rubber production last year increased 8.5% over 1986 to 2.18 million metric tons, according to the Rubber Manufacturers Association (RMA). Output in 1986 was up 7.4% from 1985. The 1987 level was the highest U.S. synthetic rubber production of this decade, surpassing the 1984 level of slightly less than 2.16 million metric tons. The all-time high in U.S. synthetic rubber production was in 1973 when more than 2.6 million metric tons were produced.

Imports of natural rubber into the U.S. account for most of the remaining rubber supply. Last year, they totaled 811,000 metric tons, up 5.4% from 1986 following a 9.4% drop from 1985.

Both exports from the U.S. and imports to the U.S. of synthetic rubber are rising, but exports are up more than two and a half times as much as imports. Last year, exports totaled 454,000 metric tons, an increase of 28% over 1986. Imports of synthetic rubber rose 11% to 283,000 metric tons, according to RMA. Subtracting last year's imports from exports puts net exports at more than 171,000 metric tons, accounting for nearly all of the increased output of synthetic rubber in the U.S. last year.

Much of last year's growth in synthetic rubber output was accounted for by SBR, production of which rose 7.4% to more than 850,000 metric tons. That was up from 792,000 metric tons in 1986. Nevertheless, SBR production remains well below the historic high of more than 1.5 million metric tons set in 1973. Exports of SBR, however, rose to 172,000 metric tons, up more than 54% from 1986. Imports, meantime, fell 14% to 83,000 metric tons. The increase in net SBR exports to 89,000 metric tons from 16,000 metric tons in 1986 exceeded the increase in

Structures of major elastomers



[a] Third monomer shown is dicyclopentadiene; ethylidene norbornene and 1,4-hexadiene are also used.

production by some 30,000 metric tons, suggesting a drawdown of inventories.

Production of polybutadiene rose about 10% in 1987 from the previous year to 371,000 metric tons. Imports increased 21,500 metric tons to nearly 82,000 metric tons, and exports climbed 37,000 metric tons to 61,000 metric tons. The decline in net imports over exports was 15,500 metric tons, a drop that accounted for nearly 45% of output growth for polybutadiene last year.

Among other synthetic rubbers, production of ethylene-propylene rubbers rose almost 11% in 1987 to more than 254,000 metric tons. Both exports and imports of these elastomers were up slightly during 1987, suggesting that most of the increased output was consumed in the U.S.

Production of all other synthetic rubbers grew at rates of 5 to 10% in 1987. Exports and imports of some of these rubbers had different patterns, with some showing declines in exports and some in imports.

For most synthetic rubbers produced in the U.S., the increase in exports accounts for a large part of the recovery in output during 1987. Growth of exports is partially a result of the declining value of the dollar. Improvement in product quality and plant efficiency by producers also is helping to spur exports.

Increased imports of tires and automobiles, combined with economic recessions, could cause U.S. consumption of these elastomers to remain below the levels of the 1970s. It's likely that growth in U.S. consumption will remain slow, with reverses during recessions likely to occur. Besides competition from imported fabricated rubber products, relatively few new products made of elastomers are coming to market. Product development in elastomers does continue, however, particularly in the area of solution polymers, which allows a polymer to be more closely tailored to a definite use than has been possible with emulsion polymers.

Some synthetic elastomers have always been made as solution polymers. Others, particularly SBR, have been adapted to solution polymerization. That process accounts for a growing share of production, although no breakdown is available on the fraction of SBR that is made using solution processes. A likely guess is that solution SBR accounts for less than 15% of total production in the U.S.

Developments such as solution polymerization of SBR to give elastomers more desirable properties for certain applications have helped keep SBR the largest-volume synthetic elastomer produced in noncommunist countries. SBR accounted for about half of that total of 5.3 million metric tons in 1986, the latest year for which data are available from IISRP.

Despite growth in use of solution SBR, emulsion SBR keeps its wide acceptance as an important rubber for making tires. Moreover, most of the emulsion SBR plants have long been paid for, except for the low costs of debottlenecking and process improvements. The two major ingredients of SBR are widely produced at low cost. Butadiene, for example, is now almost entirely recovered from coproduct streams in making ethylene. Styrene is produced by the simple alkylation of ethylene and benzene and by subsequent dehydrogenation. Benzene is widely available as an aromatic that also is coproduced with ethylene, or is made at relatively low cost during hydrocarbon reforming in petroleum refineries and then is purified.

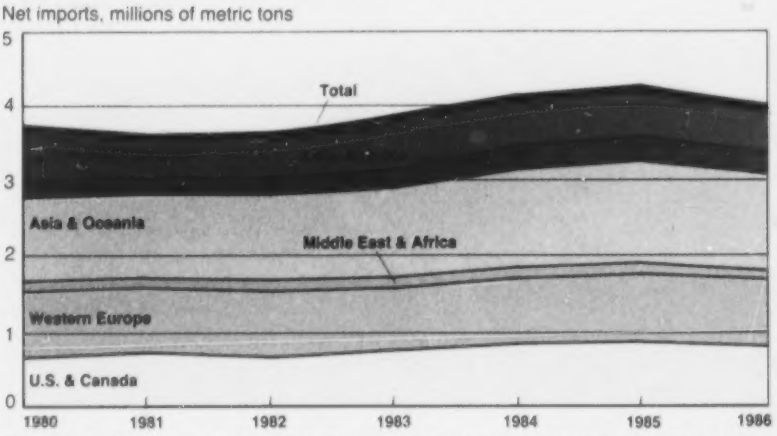
Processing simplicity of emulsion SBR continues to be an important factor helping to keep this rubber ahead of other synthetics. SBR long has been known to mix well with carbon black and other compounding materials, to form a continuous band in milling and then to extrude smoothly. The exact chemical reasons for such processing characteristics still aren't precisely known. Most rubber chemists, however, agree that the styrene configuration could be a major factor in ease of processing.

Emulsion SBR, as its process name implies, requires an emulsifying agent to stabilize an emulsion of the two hydrocarbon monomers in water, along with a variety of other chemicals such as initiators and modifiers. A common soap, such as sodium stearate, is most often used, although many kinds of soaps can go into making the various types. The soap and much of the other materials added to the emulsion are part of the finished SBR. The soap content can reach 5% or more, and the nonrubber materials in emulsion SBR may exceed 10% of the rubber weight. (This is in contrast to solution SBR, which seldom has more than 2% nonrubber materials in its finished form.)

In making emulsion SBR, the ingredients are fed continuously to a series of reactors whose temperatures are maintained at either about 5 °C or about 50 °C. The two temperatures distinguish between "cold" and "hot" emulsion SBR, and the two kinds have significantly different properties. In the last reactor, a short-stop is added to end polymerization. Unreacted butadiene then is flashed off and the unreacted styrene stripped. Afterwards, both monomers are purified and recycled. SBR is recovered from the latex in a process that may include an addition of antioxidants, extender oils, carbon black, and other chemicals, and that involves coagulation, dewatering, drying, and packaging.

Worker inspects baled raw butyl rubber at Polysar's Sarnia plant

Demand for natural rubber slipped in 1986



Note: Natural rubber produced and consumed within a region is included as an import. ■ Albania, Bulgaria, China, Czechoslovakia, East Germany, Hungary, North Korea, Poland, Romania, U.S.S.R., Vietnam, and Yugoslavia.
Source: International Rubber Study Group, London

The "hot" emulsion SBR process was developed first. It generally is allowed to run to higher conversions of the monomers, to give more branching in the polymer chain, and to give more incipient gelation. "Cold" emulsion SBR is stopped at a lower conversion and gives an elastomer that has better abrasion resistance. In tires, this property provides better treadwear. Elastomers of cold SBR also have better dynamic properties than do elastomers of hot SBR. Cold SBR elastomers generally have higher molecular weights, which allows more oil extension. All of these property differences combined have led to the replacement of most hot SBR by cold SBR in tire manufacture.

Solution SBR is made by copolymerizing styrene and butadiene in a hydrocarbon solvent (most often hexane or cyclohexane). The process usually is catalyzed (or, in the industry's terminology, "initiated") by butyllithium. The reactors and other facilities can be used interchangeably to make polybutadiene rubber. Small variations in reaction conditions and use of various branching and terminating agents are used to control properties of the finished elastomer. When polymerization is halted, and before the solvent is removed, antioxidants, oils, and other components desired in the elastomer are added.

By controlling process conditions, composition of ingredient mix, and additives, chemists can make solution SBR for tire treads with an optimum balance of wear resistance, traction, and rolling resistance. To do this, or to make an SBR for some other specific use, they control the ratio of styrene to butadiene, the distribution of styrene and butadiene units in the polymer, the ratio of vinyl, cis, and trans configurations in the butadiene units, the molecular weight and its distribution, and the amount and kind of branching. In making emulsion SBR, some of these properties, such as the ratio of styrene to butadiene, can be easily controlled. With current knowledge of the processes to make emulsion SBR, however, others are more difficult, or impossible, to control.

Besides reduction in tire sizes, the largest impact on consumption of SBR in tires has been the shift toward radial-ply passenger car tires, which tend to wear better and last longer. In building radial tires, greater stress is developed, which can cause the plies to separate in the uncured (green) tire. To overcome potential separation problems, tire builders want higher "green strength" in the rubber as it is compounded. Natural rubber provides more green strength than does SBR, resulting in the increased use of natural rubber in a radial tire at about 40% of the total rubber, in contrast with about 15% in the older, widely used bias-ply tire.

Use of SBR as a share of total rubber in larger size truck and bus tires always has been lower than in passenger car and light truck tires. At high tire loads, SBR has poorer dynamic properties that lead to heat buildup and shorter life and has lower abrasion resistance than do some other rubbers. Blends of polybutadiene rubber and natural rubber are more heavily used in truck tires to provide longer life.

Nontire uses of SBR take about 25% of consumption. A big share of these uses are in automotive applications (where SBR often is blended with other elastomers), such as hoses, belts, grommets, seals, and various extruded or molded items. Automotive, nontire consumption rises and falls with production of cars and trucks and with changes in physical property requirements of the parts, especially requirements involving service life and operating temperature.

Other nontire and nonautomotive uses of SBR range over most industries that require hoses, belts, gaskets, seals, and other extruded and molded products. SBR also goes into footwear, various kinds of solid wheels, roll covers, coated fabrics, and wire and cable insulation. A sizable quantity of SBR is sold as the latex to be applied as carpet backing. The outlook for growth in this diverse range of uses is about the same as in tires. It is modest,

Wineries use Goodyear's Plicord hose to transport juices of their grapes

Synthetic rubber is significant market for many monomers

Excluding specialty rubbers, synthetic rubbers are made from the same monomers used in making many other polymers. With the exception of butadiene, synthetic rubbers are not the largest use of any of these monomers. Synthetic rubber, however, does provide a substantial outlet for the monomers, and, in some cases, may be the major use for a plant's production.

Butadiene, styrene, ethylene, propylene, isobutylene, isoprene, acrylonitrile, chloroprene (2-chloro-1,3-butadiene), and a host of other organic chemicals become synthetic rubbers by way of numerous methods of polymerization. Because of losses during polymerization, the quantity of these monomers consumed annually in making synthetic rubbers can be estimated only roughly. For making the 2.1 million to 2.2 million metric tons of the major-volume synthetic rubbers last year, more than 2.5 million metric tons (5.5 billion lb) of the monomers would be required.

Butadiene, as the 1,3-isomer, is consumed in far larger quantities than any other monomer for synthetic rubber. In 1987, an estimated 850,000 metric tons of styrene-butadiene rubber and 365,000 metric tons of polybutadiene, plus additional quantities of other elastomers containing butadiene, were produced in the U.S. The other elastomers that require significant quantities of butadiene are polychloroprene and nitrile rubbers. More than 80% of U.S. butadiene consumption goes into elastomers of one kind or another; that's about 2.75 billion lb of the estimated U.S. consumption of 3.3 billion lb in 1987.

In 1987, prices of butadiene nearly tripled, rising from about 11.5 cents per lb in January to at least 32 cents per lb in October. (Prices were as low as 9 cents per lb in October 1986, down from 28 cents per lb in January of that year.) Since fall 1987, prices have weakened as supplies improved, dropping to 26 cents per lb in February of this year and rumored to go as low as 23 cents per lb this month.

Two factors affected butadiene supply in 1987. One was a temporary reduction early in the year of output from steam crackers, where butadiene is a coproduct of ethylene. The other was a reduction in imports of butadiene during 1986 and early 1987, as demand in Europe improved. Net imports of butadiene in 1986 were less than 275 million lb, down from more than 640 million lb in 1985. As a result, inventories of butadiene fell. Imports surged, however, during the second half of 1987, totaling 650 million lb through November. That surge contributed to increased inventories, and prices tumbled about 20%.

Both inventories and imports of butadiene are forecast this year to stay above 1987 levels. As a result, the temporary scrambling that some elastomer producers did in 1987 likely will not be repeated in 1988. If current prices are an indication of the level for the whole year, raw materials costs for elastomers containing butadiene could ease.

Styrene, consumed mainly in SBR, various styrene-butadiene latices, and thermoplastic elastomers, ranks next to butadiene as the largest-volume mono-

especially as long as large quantities of natural rubber are available at competitive cost and as long as other synthetic elastomers are available with better physical properties for certain uses.

In noncommunist countries, polybutadiene rubber is produced second in volume to SBR. Its polymerization processes are similar to those of SBR, although most polybutadiene rubber is made by the solution process. Either of the double bonds of butadiene can react during polymerization. The resulting polymer can contain a wide range of geometric isomerism. If both of the double bonds enter the reactions, a 1,4-addition results to give either the *cis*-1,4- or *trans*-1,4- configuration. If just one double bond reacts, a vinyl or 1,2- addition results with three possible configurations—isotactic, syndiotactic, and atactic. Depending on the kind of polymerization process used and the catalyst system, a wide range of compositions of polybutadiene configurations can be made.

Processing and fabrication of polybutadiene depends on polymer properties, but in general, this rubber processes with more difficulty than SBR. As a result, polybutadiene often is blended with SBR to improve milling and other characteristics. Improved wet skid resistance of tire treads and improved traction are two reasons for the blending of polybutadiene with SBR and natural rubber. The contributions of polybutadiene in tires include good resistance to wear and groove cracking, lowered rolling resistance, and low heat buildup.

As a result, tire uses of polybutadiene elastomers, which include all kinds of tires and retreading rubber, amount to about 80% of U.S. consumption. Most of the remaining use of polybutadiene is as an impact modifier for polystyrene and other resins by graft polymerization. Impact-modified polystyrenes include polybutadiene contents in the range of 2 to 10%. The remainder of polybutadiene elastomer consumption is in various extruded and molded industrial rubber products.

In terms of production, ethylene-propylene elastomers rank next in size to polybutadiene. The copolymers are produced in much lower volumes than are the terpolymers, with terpolymers accounting for about three quarters of U.S. output. The third type of monomer (known as dienes) in terpolymers of commercial significance is either dicyclopentadiene, ethylidene norbornene, or 1,4-hexadiene. Each of these termonomers produces different characteristics in the final elastomer. Dicyclopentadiene yields elastomers with the slowest cure rates of the dienes and gives a polymer with branched chains, as a result of its second double bond having low reactivity. Ethylidene norbornene, made by reacting butadiene with cyclopentadiene, may be the widest used of the termonomers because it is the most easily incorporated into the polymer. The double bond, so introduced, improves sulfur vulcanization. Both linear and branch-chain terpolymers with desired final properties can be made with ethylidene norbornene by varied polymerization conditions. Use of

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mer going into elastomers. In 1987, those uses likely totaled more than 800 million lb. However, SBR required only about 40% of the total going into elastomers, a little more than 10% of total production of about 7.9 billion lb.

Styrene supplies became tight worldwide during 1987. Elastomer producers in the U.S. and Canada who use styrene as a polymer component had less difficulty getting it than they did getting butadiene. Demand for styrene to make polymers and for export grew rapidly in 1987, and prices rose accordingly. Demand for styrene remains strong and prices are relatively firm around the world.

Production of styrene in the U.S. is expected to increase slightly through debottlenecking programs. The size of capacity additions likely will be small—less than 5% increases. And producers will continue to run their plants all out as they did in 1987.

Isobutylene, highly purified, is the primary monomer for the various butyl elastomers. The U.S. has only one producer, Exxon Chemical. Data on production of butyl elastomers are put in the "all other" category. As a result, no accurate estimate of isobutylene consumption in these elastomers is possible. Based on estimated demand growth for butyl elastomers on the latest available data, isobutylene use for elastomers may be around 300 million lb per year. That volume is but a small part of total isobutylene production from both refinery catalytic and steam cracking.

Ethylene and propylene, used in making ethylene-propylene and ethylene-propylene-diene elastomers, are produced in volumes of about 35 billion lb and 20 billion lb, respectively. The elastomers this year will require about 500 million to 600 million lb of the two olefins, a small part of total consumption. As a result, no supply difficulties will be experienced, although raw material costs will be up because of the nearly doubled prices for the olefins.

Isoprene, or 2-methyl-1,3-butadiene, production in 1986 was reported at just under 140 million lb by the U.S. International Trade Commission. Because isoprene for use in making polyisoprene elastomer and other elastomers is purified from C_5 streams from cracking, not all production may have been reported because of the low concentrations. Apparently, sufficient isoprene is recovered to meet demands from elastomer manufacture and will continue to be, since production of elastomers requiring it is growing slowly.

Acrylonitrile, used in nitrile elastomers as a copolymer with butadiene, is produced at a rate of about 2.5 billion lb per year. Nitrile elastomers will require about 50 million lb of acrylonitrile this year, making it likely that no supply problems will be encountered by its producers.

Chloroprene is made into neoprene elastomers—the production of which is no longer reported. The two U.S. producers, Du Pont and Mobay Synthetics, make their own monomer. Based on historical elastomer production data, monomer output probably totals about 250 million lb per year.

1,4-hexadiene as the third comonomer will give elastomers having good processing characteristics and heat resistance.

Most ethylene-propylene elastomers are made in a solvent such as hexane, using Ziegler-Natta catalyst systems for polymerization. After polymerization is stopped, the unreacted monomers are flashed off and recovered. If wanted, extender oils can be added before the solvent is removed and the polymer prepared for packaging.

A wide range of compositions is possible for the co- and terpolymers. Most commercial grades of copolymer elastomers have 40 to 60% ethylene in them. Commercial grades of terpolymers, often abbreviated EPDM, have about the same ratio of ethylene to propylene and up to about 10% of diene.

Curing, or vulcanization, of the ethylene-propylene elastomers varies, depending on whether a diene is present. The copolymers are considered to be saturated elastomers and therefore require a peroxide cure, although sometimes sulfur also is present. The terpolymers most often are cured with conventional sulfur-containing recipes. Cures are differentiated to fit the polymers, which, in turn, often are specifically made for the type of fabrication—extrusion, molding, or calendering—expected to be encountered.

The automotive market (excluding lubricating oil additives) is still the largest for ethylene-propylene elastomers, although some nonautomotive uses are growing faster now. Tire use is small, with most of the ethylene-propylene rubber going into the white strip on passenger car sidewalls. Automotive uses predominantly are in hoses, seals, grommets, and weather stripping. Additional quantities of this elastomer are blended with polyolefins to make thermoplastic olefin elastomers that go into bumper parts, some exterior body parts such as fender extensions and rub strips, wire and cable coverings, and numerous other items.

Nonautomotive uses of these elastomers cover a wide range. For a while, use in single-ply roofing increased rapidly. Now this application has slowed as capture of this market has reached high levels. Copolymers have had recent rapid growth as viscosity-index improvers in lubricating oils, particularly the multiviscosity-grade oils because of cost-performance characteristics. Other uses of ethylene-propylene elastomers include modifiers for thermoplastics (to give improved impact and stress crack resistance), wire and cable insulation (particularly for exterior applications), hoses of many kinds, appliance parts, and other extruded and molded products.

Polyisoprene, another widely used synthetic rubber, is made in a process similar to that for polybutadiene—an addition polymerization. Because of the 1,3-diene structure of isoprene, the reaction can involve the same three double bond positions as in butadiene and can yield the different configurations. Of the eight possible arrangements for polyisoprene, three have been isolated: the *cis*-1,4-, *trans*-1,4-, and atactic-3,4- forms. Polymerization is carried out in a hydrocarbon sol-

← CIRCLE 34 ON READER SERVICE CARD

vent using Ziegler-Natta catalyst systems. Depending on the makeup of the catalysts, a very high content of *cis*-1,4-polyisoprene can be made, although it is not so high as is found in natural rubber polymer, in which it may be more than 99%.

Because of its similarity to natural rubber, the *cis*-1,4- form of polyisoprene is used mostly in making tires. With additives, it will provide tires with about the same level of green strength as will natural rubber. Most polyisoprene used in passenger car and light truck tires goes into sidewalls because blends of polybutadiene rubber provide better properties for treads. More polyisoprene, as a share of total rubber content, goes into truck and bus tires where it is substituted for natural rubber in blends with polybutadiene to provide the properties of good resistance to heat buildup and good abrasion resistance in treads. Consumption of polyisoprene in tires likely will grow slowly, especially since radial tires have replaced most bias tires for passenger cars.

Nontire uses of polyisoprene elastomers account for about 40% of consumption. In many of those uses, the elastomers substitute for natural rubber, depending on the price of natural rubber. The fabricated forms of rubber products made of polyisoprenes are the same as those made of other rubbers. These products are mechanical goods, made by extrusion or molding, for automotive and other industries, footwear, and many other smaller-volume items. Nontire uses probably will grow 3 to 5% annually, as influenced by fashion in footwear, auto production, and developments in other fields such as medicine.

An interesting aspect of polyisoprene is that capacity for making the polymer in the U.S.S.R. is estimated by IISRP to be more than 1 million metric tons per year, several times the combined capacity in noncommunist countries. The reason for such large capacity in communist countries apparently is to minimize dependence on natural rubber, now slightly more than 20% of total new rubber consumption in those countries.

Butyl rubbers (including the halobutyl rubbers) also are important tire elastomers. Butyl use in tires is almost exclusively as the inner liner for tubeless tires and in tubes for tires, because of its very low air permeability compared to natural rubber or SBR. Butyl elastomers are copolymers of isobutylene and a small amount of isoprene. The commercial halobutyls are either chloro- or bromo- derivatives.

Butyl elastomers are made by polymerizing a solution of isobutylene and isoprene in methyl chloride, using aluminum chloride as the catalyst at about −100 °C. The reaction is fast and exothermic. During polymerization, a slurry forms of butyl elastomer and the solvent. The polymer-hydrocarbon solvent slurry is contacted with hot water in a flash drum where most of the unreacted monomers and solvent are removed overhead. An antioxidant and zinc stearate is added to the polymer to prevent breakdown and agglomeration. The polymer-water slurry then goes to a vacuum-stripper to remove residual hydrocarbons and then to a dewatering extruder. From there, it goes to a drier.

To make halogenated butyl elastomers, the elastomer is dissolved in a hydrocarbon solvent, usually hexane, and treated with chlorine or bromine in a high-intensity mixer. Coproduct halogenic acids are neutralized with dilute aqueous caustic solution. After neutralization, the caustic phase is separated from the mixture, the polymer-solvent stabilized, and an antioxidant added. The finishing steps are similar to those for nonhalogenated butyl elastomers.

Vulcanization of both kinds of butyl elastomers can involve a variety of techniques, ranging from use of a conventional sulfur crosslinking, through use of dioximes, to use of bis-alkylation with such compounds as primary diamines. The elastomer and its selected cure depends on the final end use and on the fabricated form of use. For example, a butyl rubber to be used for an exterior cable insulation requiring high ozone and weather resistance would be of a type that has low unsaturation in the polymer and a cure system containing *p*-quinone dioxime.

Besides ozone and weather resistance, butyl elastomers can be tailored to have good thermal stability (for elastomers), vibration damping characteristics, and chemical and moisture resistance. Tire components require the largest share of butyl elastomer consumption in the inner liners as well as in sidewalls. Some of the other uses are in seal-

Synthetic rubber capacity tops 12 million metric tons

a Albania, Bulgaria, China, Czechoslovakia, East Germany, Hungary, North Korea, Poland, Romania, U.S.S.R., Vietnam, and Yugoslavia. b Afghanistan, Australia, Bangladesh, Burma, Cambodia, India, Indonesia, Japan, Laos, Malaysia, New Zealand, Pakistan, Philippines, South Korea, Sri Lanka, Taiwan, and Thailand.
Source: International Institute of Synthetic Rubber Producers

U.S. tire production holds below decade-old peak . . .

Millions of units	Passenger car	Truck & Bus	Total
1977	193.4	38.2	231.6
1978	183.2	40.2	223.4
1979	168.0	38.7	206.7
1980	130.9	28.4	159.3
1981	149.8	32.0	181.8
1982	149.5	29.0	178.5
1983	156.3	30.7	186.9[a]
1984	172.9	36.4	209.4[a]
1985	162.6	33.3	195.9
1986	159.4	30.9	190.3
1987[b]	168.3	35.8	204.1

a 0.1 difference due to rounding; b C&EN estimate based on 10-months reported production.
Source: Rubber Manufacturers Association

. . . as tire imports climb to more than 20% of output

Millions of units	Passenger car	Truck & Bus	Total
1977	13.0	4.1	17.1
1978	12.9	4.3	17.2
1979	15.2	4.8	20.0
1980	13.7	4.3	18.0
1981	17.5	3.9	21.4
1982	16.9	3.7	20.6
1983	23.0	4.5	27.5
1984	30.1	6.6	36.7
1985	32.8	7.8	40.6
1986	34.0	7.6	41.6
1987[a]	38.9	8.8	47.7

a C&EN estimates based on 10-months reported imports. **Source:** U.S. Department of Commerce

ants and adhesives, hoses, gaskets, pads for truck cabs, bridge bearing mounts, and in other places where vibration damping is important. Growth in demand for butyl elastomers clearly depends on tire production, which probably takes 75% of consumption.

Polychloroprene elastomers are polymers of chloroprene, 2-chloro-1,3-butadiene, that are made by an emulsion polymerization using a rosin soap as the emulsifying agent and using an initiator of an alkali persulfate with sulfur present. Variations in the polymerization process lead to a large number of different elastomers (both solid and latex forms) designed for specific uses. Polychloroprenes generally are noted for their resistance to abrasion, hydrocarbons, sunlight, ozone, and weathering, and for their tough-

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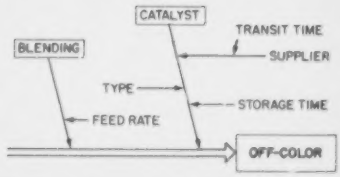

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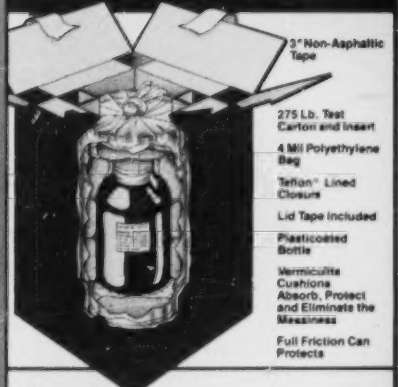
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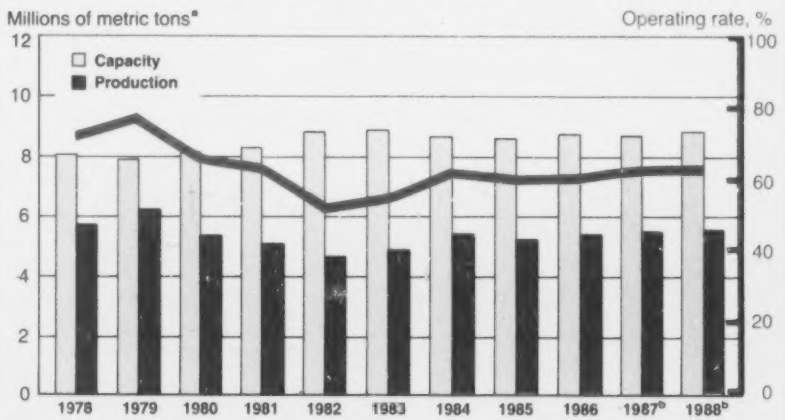
ness. They also are noted for being more difficult to compound than most synthetic elastomers.

Uses of polychloroprene elastomers range from adhesives to wire coverings. Other than small amounts in some tire sidewalls, polychloroprene elastomers are not used in tires. The largest use is in making mechanical rubber goods for automotive, petroleum production and transportation, construction, and consumer products. Those uses all take advantage of polychloroprene's properties. For example, in oil production and transportation, the elastomers are fabricated into well packers, other seals, gaskets, and hoses. Latices are used in making gloves, adhesives, and binders.

More than 200,000 metric tons of nitrile elastomers were produced in the noncommunist countries in 1987, a production level that has changed very slowly during recent years. In the U.S., the production of solid nitrile rubber by its four producers—Copolymer Rubber & Chemical, B. F. Goodrich, Goodyear Tire, and Uniroyal Chemical—totaled more than 68,000 metric tons and was the highest of this decade. The net of imports over exports of nitrile elastomers added about 4000 metric tons more to the supply.

Global capacity use for synthetic rubber has turned up



Note: Data include latices but exclude specialty rubbers. **a** Excludes communist countries. **b** C&EN estimate.
Source: International Institute of Synthetic Rubber Producers

Nitrile elastomers are copolymers of acrylonitrile and butadiene with properties varying, mainly depending on the composition of the polymers. Elastomers with high acrylonitrile content (40 to 50%) generally have higher resistance to hydrocar-

Everything.

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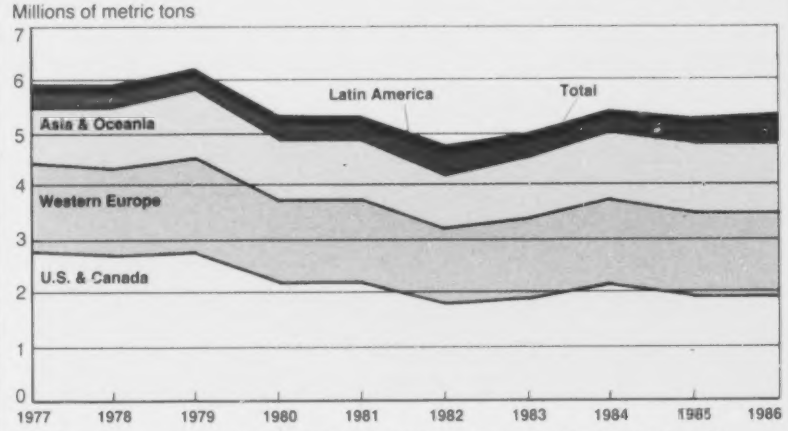
bons and abrasion and lower permeability to gases. Elastomers with low acrylonitrile content (about 20%) are more resilient and retain resilience at lower temperatures.

The polymerization processes for nitrile rubbers are similar to those used for emulsion SBR and are operated either as hot or cold and as batch or continuous processes. Soaps, catalysts, and other components of the recipe may be specifically different from those used in making SBR, but often they are chemically similar. Because nitrile elastomers are resistant to hydrocarbons, oil extension rarely is used in the polymer finishing process.

Because of their hydrocarbon-resistant property, nitrile rubbers mostly are used to handle oils, fuels, and chemicals, in the form of hoses, tubing, gaskets, seals, and packers. These fabricated items go into transportation equipment of all kinds, food processing, and crude petroleum production items. Various nitrile elastomers also are used to modify plastics such as polyvinyl chloride and acrylonitrile-butadiene-styrene to impart impact resistance. Uses of the latex form include paper saturation for masking tapes, building papers, and label stock. Competition is strong, however, so the outlook for growth in demand for nitrile elastomers is low.

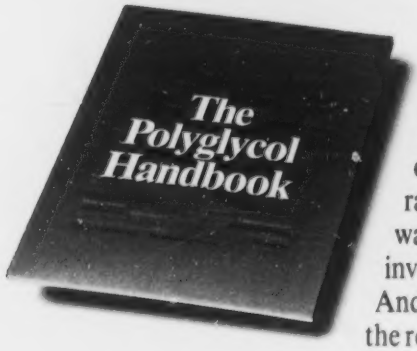
Nitrile elastomers are sometimes put into the category of specialty elastomers, which can include the

Production of synthetic rubber holds below peak levels



Note: Excludes communist countries. South African production is included with Asia & Oceania for 1977 to 1979, Latin America for 1980 to 1982, and Western Europe for 1983 to 1986.
Source: International Institute of Synthetic Rubber Producers

From stop to bottom.



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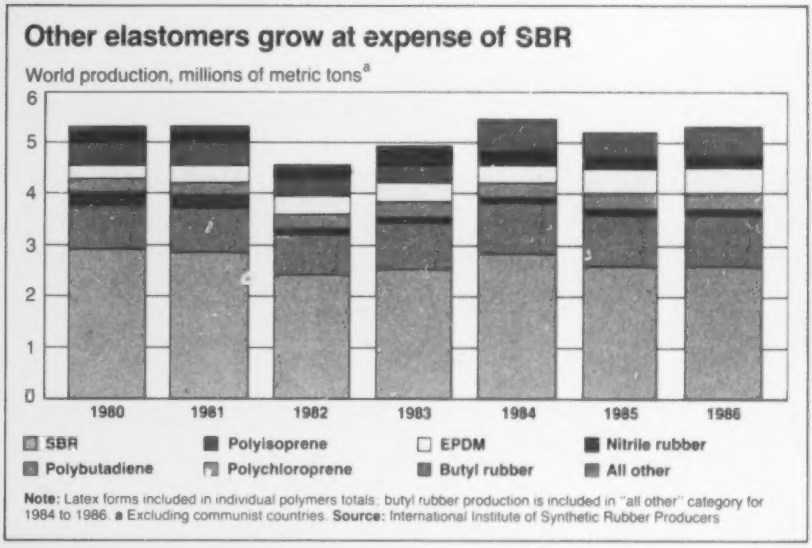


polyurethanes, silicones, fluorocarbons, thermoplastics, and others. Except for the the major-volume elastomers and nitrile, polyisoprene, and polychloroprene elastomers, production and use patterns for other elastomers are not available from industry groups. For this "all other" group, IISRP reports noncommunist countries' production at more than 500,000 metric tons in 1986. U.S. production in 1987 of all other elastomers, including polyisoprene, totaled 638,000 metric tons, up from 596,000 metric tons in 1986, according to RMA.

Among the specialty elastomers, the polyurethanes have become the most widely used, with estimates of total production at more than 200,000 metric tons per year. The diversity among producers, the forms, and the uses make definitive data impossible to obtain. These elastomers can be made by solution, suspension, and melt polymerization, all from a variety of monomers, into polymers that are fabricated by casting, molding by different methods, milling, and other means. The uses include tires (usually solid), gaskets, automotive body parts, many kinds of hoses and cable coverings, and consumer products as in seating.

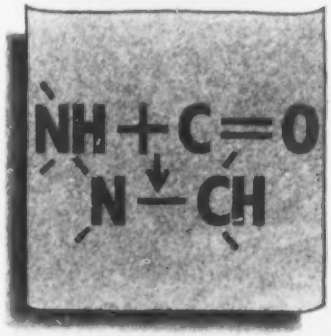
Silicone elastomers probably are second in size among the specialty elastomers after polyurethanes, excluding the nitriles. U.S. production is about 25,000 metric tons annually, but such a figure cannot be verified. Even though silicone elastomers have high prices, their use can be justified in applications demanding high resistance to heat, weather, and compression-set. Automotive mechanical goods and construction sealants are the major uses of these elastomers.

A large number of other specialty elastomers are made throughout the world. There is lack of agreement on whether some products are true elastomers, whether other products also should be included in this category, and whether products are produced in sufficient volume to be a commercial specialty elastomer. Some of the specialty elastomers have been commercially available for a long time. For example, polysulfide elastomers were offered more than 50 years ago. Some, such as thermoplastic elastomers, are produced in larger volumes than are some general-purpose elastomers, although data on thermoplastic elastomers output are elusive.

These specialty elastomers provide an extensive array of physical property, cost, and performance characteristics. Many are expensive, but because they meet demanding conditions of use, they are worth the cost. Uses include automotive items, aerospace equipment, medical devices, pollution control equipment, and a host of other industrial components.

The specialty elastomers, as a group, add little to the total volume of elastomer production, but they are profitable for producers. □

Reductive Amination.



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